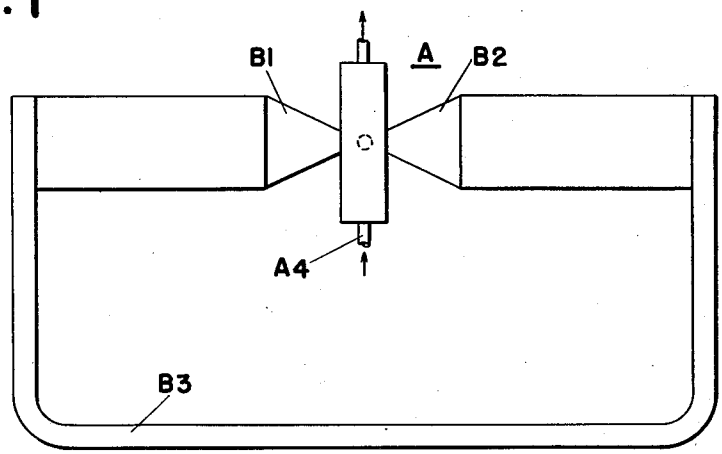
July 22, 1952 R. S. MEDLOCK 2,603,965

PARAMAGNETIC GAS ANALYZER

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Fig. 1



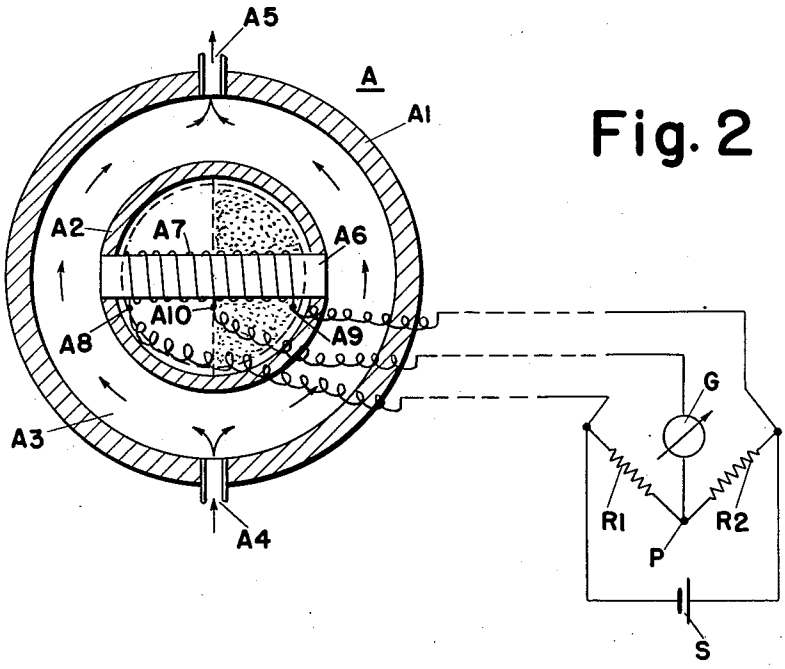


Fig. 2

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Fig. 3

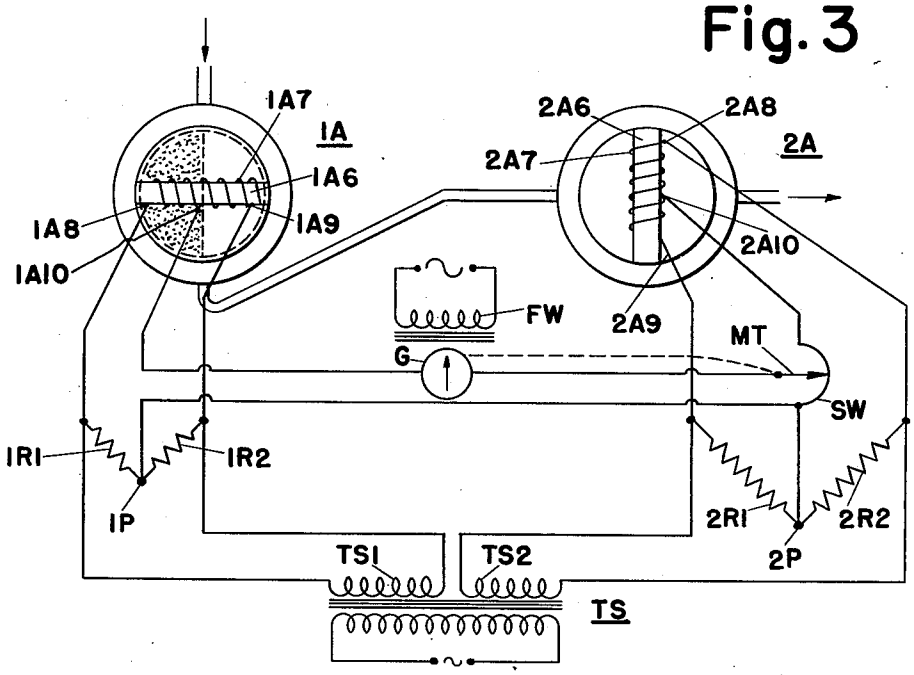
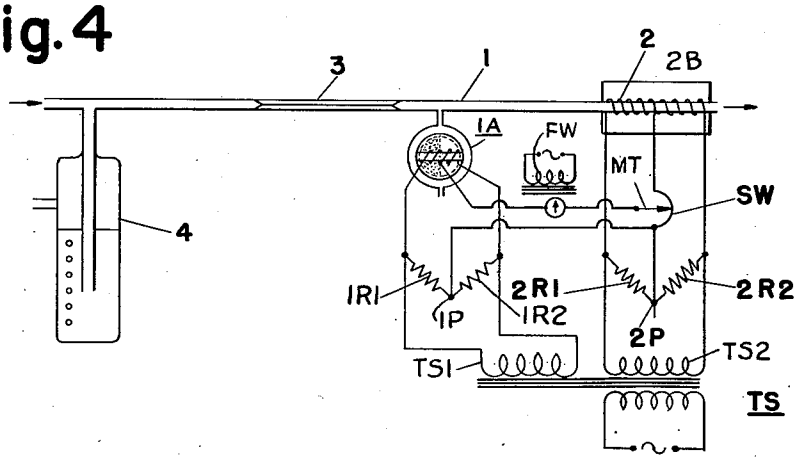


Fig. 4



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PARAMAGNETIC GAS ANALYZER

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10 Claims. (Cl. 73—27)

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This invention relates to apparatus for assessing the amount of a gas of relatively high magnetic susceptibility contained in a mixture of gases. The primary, though not exclusive, application of the invention is to the assessing of the oxygen content of gas mixtures.

Oxygen has a magnetic susceptibility much greater than that of any other gas except nitric oxide and closely obeys the Curie law according to which susceptibility varies inversely with absolute temperature. This fact has been utilized in known apparatus for assessing oxygen content.

The invention is illustrated in and explained in connection with the accompanying drawings in which Figures 1 and 2 show a known apparatus, Figure 1 being a schematic representation of the general arrangement and Figure 2 being a diagrammatic view showing the cell A, bridge and connections; while Figure 3 is a diagrammatic representation of one embodiment of the invention; and Figure 4 is a diagrammatic representation of a modification.

In order that the invention may be the better understood a known oxygen content assessing apparatus utilising the above general principle will first be described with reference to Figures 1 and 2.

In the known apparatus of Figures 1 and 2 the gas is passed through an analysis cell generally designated A and consisting of a cylindrical housing A1 in which is a concentric central portion A2 which, with the housing, defines an annular space or flow-channel A3. The gas to be tested enters the annular space through the housing wall at A4 at one end of a diameter and leaves the housing at A5 at the opposite end of said diameter so that there are two equal and similar gas paths one each side of the central portion as indicated by the arrows in Figure 2. Diametrically across the central portion is a horizontally arranged cross-tube A6 whose length is at right angles to the diameter on which the entry and exit ports for the gas are positioned, said tube communicating at both ends with the annular space A3. On the tube is wound a suitable heater winding A7 which is symmetrically arranged thereon and is provided with end connections A8, A9 and a centre tap connection A10. The whole analysis cell is mounted between the pole pieces B1, B2 of a permanent or other magnet system B3 (see Figure 1) and the said pole pieces and the central portion of the cell are so arranged that the magnetic flux, which passes at right angles to the length of the tube A6 and to the general plane of the cell, is concentrated

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in one-half only of the central portion of the cell. In Figure 2 this half is indicated conventionally by dotted shading. In other words, the arrangement is such that practically all the magnetic flux passes through the central portion of the cell to one side (in Figure 2 the right hand side) of the diameter on which the entry and exit ports for the gas are situated, the other half of the central portion carrying as nearly as possible zero flux or, at any rate, only unavoidable leakage flux. The two halves of the heating winding on either side of the centre tap are associated with a resistance bridge or the like in any convenient way. For example, as indicated in Figure 2 the ends A8, A9 of the winding may be connected to the opposite ends of a resistance consisting of equal elements R1, R2 across which a potential is applied, from any convenient suitable source S, the middle point P between the resistance elements being connected through a galvanometer G to the centre tap A10.

With this arrangement when gas is passed through the cell and current is fed to the heating winding the portion of the gas in the horizontal tube A6 will become heated and, if it contains oxygen, its magnetic susceptibility will decrease there. In consequence there will be a tendency for the unheated gas in the annular space of the cell to be attracted into the magnet field to displace the heated gas there. The fresh or displacing gas when it reaches the portion of the tube in the magnetic field is in turn heated and replaced by cool gas. Accordingly, a continuous flow of gas occurs through the horizontal tube from the half in the magnetic field to the half which is out of the magnetic field, i. e., from right to left in Figure 2. If, therefore, the bridge is balanced before the heating current is switched on it will become unbalanced to an extent which depends, among other things, upon the oxygen content of the gas. The degree of unbalance may be employed to indicate or record the oxygen content or to produce some desired control action in dependence thereon. If the gas contains no oxygen, there is no tendency for flow within the tube A6 because the magnetic field is in such case ineffective to induce flow of the gas and because the ends of the tube A6 communicate with regions of the annular space A3 between which there is no pressure differential. In brief, the rate of flow of the gas in thermal-transfer relation to both halves of the temperature-sensitive resistor A7 is a function of the percentage of oxygen in the gas.

While an apparatus as above described responds

faithfully in dependence upon oxygen content it is unfortunately not dependent only upon oxygen content but also upon the specific heat and viscosity of the gas. It may be shown that in an apparatus as above described the equation defining the E. M. F. developed across the galvanometer or other responsive member of the bridge includes also the factors of specific heat of the gas (the E. M. F. is directly proportional to this) and the co-efficient of viscosity of the gas (the E. M. F. is inversely proportional to this). Accordingly alteration of specific heat or viscosity; both of which occur with change of gas temperature and composition, affect calibration of the apparatus and such calibration is apt, with known apparatus, to be difficult and to require a good deal of careful checking and calculation. The present invention seeks to avoid these difficulties.

According to this invention an apparatus for assessing the amount of a gas of relatively high magnetic susceptibility in a mixture of gases and of the kind in which the gas is passed through a cell wherein it is subjected to localised heating in the presence of a magnetic field so as to induce a flow of gas in dependence upon change of susceptibility due to heating thereby to produce a response in dependence upon said flow is characterised by the provision of correction means wherein the gas is heated in the absence of a magnetic field but so as to produce a flow in dependence upon the said heating, the specific heat of the gas and the viscosity thereof and wherein a response is obtained in dependence upon said flow, the whole arrangement being such that the response due to specific heat and viscosity in said correction means substantially cancels the response due to the same causes in the cell, the two responses being combined to produce a net response dependent substantially only upon the magnetic susceptibility of the gas.

Preferably the correction means comprise a second cell similar to the first except that there is no applied magnetic field, and that the heating is arranged to produce a convectional flow of the gas. Preferably also the heating in the cell and in the correction means is produced by electrical heating windings arranged to be differently cooled in different parts thereof in dependence upon the gas flows therethrough, thereby to produce electrical responses in dependence upon said gas flows.

It will be seen that since the response given by the first or main cell is dependent upon magnetic effects, specific heat effects and viscosity effects whereas the response given by the correction means is dependent on specific heat effects and viscosity effects only, the net result is that desired namely an indication or other output dependent upon magnetic effects only.

Figure 3 shows one embodiment of the present invention utilising two cells, namely a first cell 1A and a reference cell 2A. In Figure 3 references including the number prefix 1 are appropriate to one cell (or its circuit) while those appropriate to the other (or its circuit) are given the number prefix 2, the same references (apart from the number prefixes) being used for corresponding parts in Figures 1, 2 and 3 and also, so far as possible, in Figure 4.

Referring to Figure 3 there is employed an analysis cell 1A and associated bridge circuit generally as hereinbefore described with reference to Figures 1 and 2, the applied voltage to the heating winding being, however, alternating instead of direct current. There is also provided a second or reference analysis cell 2A which is similar to the cell 1A except that there is no applied magnetic field and the cross-tube 2A6 which is across the central portion thereof and provided with the centre-tapped heating winding 2A7 is vertically instead of horizontally arranged. In the second cell 2A, therefore, due to the vertical arrangement of the tube 2A6, gas flow will occur due to convectional effects on heating so that the flow of gas through the central tube will be a function of the viscosity of the gas and the temperature difference between the two halves of the heater winding will be a function of the specific heat and viscosity of the gas. In absence of heating of the gas by winding 2A7, there is no tendency for flow within the tube 2A6 since the ends thereof communicate with regions of the annular flow channel between which there is no pressure differential. The electrical circuit used with the two cells is a simple combined bridge circuit. In the example shown a centre tapped resistance bridge consisting of the equal elements 1R1, 1R2, is connected across the outer terminals 1A8, 1A9 of the heater winding 1A7 of the first cell 1A and a similar centre tapped resistance bridge comprising the equal elements 2R1, 2R2 is connected across the outer terminals 2A8, 2A9 of the heater winding 2A7 of the second cell 2A. Alternating current is supplied through a transformer TS having two secondaries TS1 and TS2 one of which is across one resistance bridge and the other of which is across the other. The centre point 2P of the resistance bridge of the second or reference cell is connected to the centre tapping 2A10 of the heating winding 2A7 of that cell through a resistance slide wire SW, a movable tap MT on which is connected through a galvanometer G having an A. C. field winding FW to the centre point 1A10 of the heating winding 1A7 of the first cell. The centre points 1P, 2P of the two resistance bridges are directly connected together to complete the circuit.

Where the arrangement is required to effect a control, or operate a recording instrument or the like the movable point on the slide wire may be arranged to be automatically controlled by the galvanometer by any convenient known "follow-up" system (not shown), so that it is automatically moved to correct for any out of balance which may occur. Such automatic movement is then available for indication of the oxygen content or for recording or for producing the required control action. The gas to be tested may be passed through one cell and then through the reference cell (as in Fig. 3) or a parallel arrangement of the two cells may be employed as regards gas flow (as in Fig. 4).

It will be noted that with arrangements in accordance with this invention in which two bridge circuits are employed and the output of one is measured in terms of the ratio to the output of the other, inherent voltage compensation is obtained—an incidental but important practical advantage.

The invention is not limited to the particular apparatus described and other arrangements adapted to provide compensation for variations due to specific heat and viscosity may be employed. For example, as indicated in Figure 4, the compensation correction cell instead of being similar to the analysis cell comprises a tube 1 forming the sole gas path through the compensating cell 2B and upon which is a centre tapped heating winding 2 associated with a second bridge

as already described, Fig. 3, as comprising equal elements 2R1, 2R2 with a centre point 2P between them. The gas reaches tube 1 via a length of capillary tube 3 preceded by any convenient known form of constant head pressure regulator schematically indicated at 4 and which accordingly controls the pressure drop across the capillary tube 3 which in turn proportions the gas flow in accordance with viscosity. Specific heat correction is effected by virtue of the variation in heat transfer from one half of the heating winding 2 to the other half, heat being applied, in the example illustrated, from an A. C. source through transformer TS.

Thus as in Fig. 3, the gas flow through the compensating cell is a function of the viscosity of the gas being analyzed and the temperature difference between the two halves of the heater winding, or paired resistors of the compensating cell, is a function of the specific heat and viscosity. In brief, as in Fig. 3, the correction cell and its associated bridge circuit produces a response in dependence upon the specific heat and viscosity of the gas which substantially cancels the response due to the same causes in the analysis cell and its bridge circuit so that in consequence the net response of the two cells and networks is dependent substantially solely on the magnetic susceptibility of the gas.

What is claimed is:

1. A system for measuring the concentration in a gas of a component of relatively high magnetic susceptibility with correction for specific heat and viscosity of the gas comprising two cells for said gas, means for applying heat and magnetism to one of said cells and heat only to the other of said cells to effect in said cells different flow rates similarly affected by the specific heat and viscosity of the gas, said heat-applying means comprising electrically heated windings whose resistances respectively vary with changes of the flow rates in said cells, electrical networks respectively including said electrically heated windings and connection with their outputs in opposition, a responsive device in circuit with said networks, and adjustable impedance means connected to effect null response of said device by balancing the output of one of said networks against an adjustable fraction of the output of the other of said networks, the setting of said impedance means at balance being a corrected measure of the concentration of said component of high magnetic susceptibility and the extent of adjustment between successive balances being a corrected measure of the change in concentration of said component.

2. A system for measuring the concentration in a gas of a component of relatively high magnetic susceptibility with correction for specific heat and viscosity of the gas comprising two cells for said gas, means including a magnet and an electrically heated winding for inducing in one of said cells a gas flow dependent upon the magnetic susceptibility, the specific heat and viscosity of the gas, means including an electrically heated winding for inducing in the other of said cells a gas flow dependent upon the specific heat and viscosity of the gas, electrical networks respectively including said electrically heated windings, a source of alternating current for said networks whereby the output of each is an alternating current voltage varying in accordance with the flows in said cells as respectively induced by their aforesaid flow-inducing means, a responsive device in circuit with said networks, and adjustable impedance means connected to effect null response of said device by balancing the alternating-current voltage output of the network including said one of the cells against an adjustable fraction of the alternating-current voltage output of the network including said other of the cells, the setting of said impedance means being a corrected measure of the concentration of said component of high magnetic susceptibility.

3. A system for measuring the concentration in a gas of a component of relatively high magnetic susceptibility corrected for variations in specific heat and viscosity of the gas comprising analysis cell means having a pair of temperature-sensitive resistors disposed along a single path in which there is no flow of gas in absence of applied heat and magnetism, said pair of resistors being included in branches of a circuit to produce an output signal, means for applying heat and magnetism to the gas in said analysis cell means to effect flow thereof successively past said resistors, the resulting temperature difference of the resistors of said analysis cell means producing an output signal magnitude which is zero in absence of said component and which for presence of said component varies in dependence upon the magnetic susceptibility, the specific heat and the viscosity of the gas, correction cell means having a second pair of temperature-sensitive resistors disposed along a single flow path in which there is no flow of gas in absence of applied heat, said second pair of resistors being included in other circuit branches to produce a second output signal, means for applying heat in the absence of magnetism to the gas in said correction cell means to effect flow thereof successively past the resistors of said second pair, the resulting temperature difference of the resistors of the correction cell means producing a second output signal magnitude which varies in dependence upon the specific heat and viscosity of the gas, and electrical means upon which is impressed the output signals respectively produced by the paired resistors of said analysis cell means and the paired resistors of said correction cell means to provide a resultant which is zero in absence of said component and which in presence of said component is substantially solely dependent upon changes in magnetic susceptibility of the gas.

4. A system as in claim 3 in which the electrical means is in the output circuit of two bridges respectively including the paired resistances of the analysis cell means and the correction cell means and whose unbalances respectively vary with the temperature difference therebetween, said bridges being connected to effect mutual cancellation of unbalances due to the specific heat and viscosity of the gas.

5. A system as in claim 3 in which both cell means each has an annular flow-channel for divided flow of the gas and a cross-tube connected to diametrically opposite points of the annular channel with the paired resistors side-by-side along the axis of the cross-tube, the axes of said cross-tubes being substantially horizontal and vertical for said analysis and correction cell means respectively.

6. A system as in claim 3 in which the correction cell means is supplied with gas under control of a constant head pressure regulator through a path including a constriction and in which cell means the paired resistors are side-by-side along the flow path therein whereby the temperature difference of said paired resistors of the correc-

tion cell means is a function of the specific heat and viscosity of the gas supplied thereto.

7. An apparatus for determining the amount of gas of relatively high magnetic susceptibility in a mixture of gases subject to changes in viscosity and specific heat comprising means for supplying heating current, a first electrical network including temperature-sensitive resistance means heated by current from said supply means, an analysis cell comprising said temperature-sensitive resistance means and means for applying a magnetic field to the gas mixture in thermal-transfer relation to said resistance means to produce a flow dependent upon the amount therein of gas of relatively high magnetic susceptibility, the resistance of said resistance means of said analysis cell thereby varying in dependence upon such magnetically induced flow, the viscosity and specific heat correspondingly to vary the voltage between output terminals of said first network, a second electrical network including temperature-sensitive resistance means heated by current from said supply means, a correction cell comprising said second-named temperature-sensitive resistance means, means for effecting flow of said gas mixture in thermal-transfer relation to the resistance means of said correction cell, the resistance of said resistance means of the correction cell varying in dependence upon the viscosity and specific heat correspondingly to vary the voltage between output terminals of said second network, a responsive device in circuit with said networks, and impedance means adjustable to effect null response of said device by balancing the output voltage of one of said networks against a fraction of the output voltage of the other of said networks, the setting of said impedance means at balance being a measure of the concentration of said gas of relatively high magnetic susceptibility corrected for changes in viscosity and specific heat of the gas mixture.

8. An apparatus as defined in claim 7 wherein the correction cell is similar to the analysis cell except that there is no applied magnetic field.

9. An apparatus as defined in claim 7 wherein the flow of the gas mixture in thermal-transfer relation to the resistance means of the correction cell is effected by heating it in a substantially vertically disposed tube.

10. An apparatus as defined in claim 7 wherein the flow of the gas mixture in thermal-transfer relation to the resistance means of the correction cell is effected by a constant head pressure regulator and a constriction between said regulator and the cell.

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